





Typically, the filters are designed to reflect incident Infra-Red (IR) radiation. Other filters designed to exclude other types of optical radiation, such as Ultra-Violet (UV) radiation which may be damaging to certain components of the solar cell, may be employed. These other filters may be separate from the IR type filters. Alternatively, a single "band-pass" filter may be employed which is designed to simultaneously exclude not only IR radiation but also UV radiation from radiation incident upon a solar cell, but let "pass" through the filter optical radiation lying within a spectral band bounded by the excluded IR and UV radiations.

In general a silicon solar cell is operative responsive to radiation of wavelengths between  $0.40\mu\text{m}$  to  $1.10\mu\text{m}$ . Solar energy outside of this band is generally not converted into electricity and when absorbed only heats up the solar cell thereby reducing its efficiency. Certain types of optical band-pass filter comprise a multi-layer stack structure arranged upon a substrate, such as a glass substrate. Such multi-layer band-pass filters are designed to reflect IR radiation (or near-IR radiation) that lies immediately adjacent one side of a spectral band of radiation in respect of which a solar cell is intended to operate (e.g.  $0.4\mu\text{m}$  to  $1.1\mu\text{m}$  wavelengths), to transmit optical radiation lying within

that spectral band and to reflect UV lying adjacent the other side of the spectral band of the solar cell.

The band-pass transmission spectra of such multi-layer filters is achieved by forming the stack of layers from repeating pairs of adjacent layers in which any one layer of a pair is comprised of material having an index of refraction which differs from the index of refraction of the other layer of the pair. Thus, the resulting multi-layer stack has an index of refraction which periodically jumps between two values as the depth of the multi-layer stack increases.

As is well known to those skilled in the art, the "optical thickness" of a layer is given by multiplying the physical thickness of the layer by the index of refraction of the material of the layer for a particular wavelength of optical radiation. Thus, a layer of constant physical thickness will have an optical thickness which depends upon the wavelength of optical radiation passing through it.

By appropriately controlling the physical thickness of each of the two layers in the repeated pair of layers such that each has an optical thickness equal to  $\frac{1}{4}$  of a predetermined optical "design" wavelength (e.g. an IR

wavelength), the multi-layer stack causes reflection of optical radiation to occur not only at (and around) the predetermined "design" wavelength, but also at (and around) other wavelengths corresponding to "higher order" frequencies equal to an odd-integer multiple of the "design" frequency. The result is known as a " $\frac{1}{4}$ -wave" stack, or "interference filter".

Thus, such a quarter-wave stack may be employed as an optical filter for reflecting IR radiation by selecting the predetermined wavelength to be a suitable IR wavelength such that a reflection band is formed adjacent a desired spectral pass-band. However, a drawback of such interference filters is that the aforementioned "higher order" reflection bands often reside well within the desired spectral pass-band. Thus, such filters may well reflect radiation which it is not desirable to reflect.

Other types of multi-stack optical interference filter have been proposed in which the multi-layer stack is composed of materials having three different refractive indices rather than just two. By appropriately arranging the three different layer types in a repeating pattern within the stack of layers, the resultant structure is able to suppress the first few of the offending "higher

order" reflection bands which usually occur in simple  $\frac{1}{4}$  - wave stacks as discussed above.

However, a common feature of the simple two-index  $\frac{1}{4}$ -wave stacks and of the aforementioned three-index stacks is the presence of a discontinuity in refractive index as between neighbouring stack layers. This discontinuity arises due to the sudden change in material (and optical properties thereof) at the interface between adjacent stack layers. Such discontinuities are detrimental to the performance and structure of the filter for the following reasons.

The strength of the multi-layer stack is sensitively dependent on the degree of interfacial adhesion between adjacent stack layers. Since adjacent layers in the aforementioned prior art devices are comprised of different materials, it is often the case that the differences (either chemical and/or physical) between such neighbouring layers reduce the strength of the interfacial bond which results in the interface being a primary site of structural weakness in the multi-layer stack.

Furthermore, in existing interference filters such as those described above, the transmission spectrum thereof

at regions in between successive reflection bands are not uniformly transmissive. That is to say, although the reflection bands of such interference filters are generally mainly confined to a limited spectral band, they are in fact not fully so confined. Rather, the so-called reflection "bands" often possess significant ripples or transients of non-zero optical reflectance in the filter at spectral regions within the pass-band thereof.

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This spreading/dispersion of the reflection band into the pass-band is principally due to the discontinuity in refractive index occurring at the interface of successive layers of a stack. It is detrimental to the transmission spectrum of such filters since it attenuates optical radiation which it is intended to pass to an underlying solar cell. Hence, solar cell efficiency is reduced.

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It is an aim of the present invention to overcome at least some of the aforementioned deficiencies in the prior art. It is also an aim of the present invention to permit greater design flexibility when varying the structure of an optical filter in order to optimise its performance.

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Accordingly, in a first of its aspects, the present invention may provide an optical filter including a substrate having a plurality of layers of materials stacked upon it each of which layers is formed from one or both of:

a first material having a first index of refraction; and, a second material having a second index of refraction being less than the first index of refraction;

wherein the plurality of layers of materials include a first layer and a second layer each formed from an inhomogeneous mixture of said first material and said second material and a third layer formed from the first material being stacked in between the first layer and the second layer wherein the optical thickness of each of said first and said second layers is greater than the optical thickness of said third layer.

Due to the inhomogeneous mixing of the first material and the second material, when forming the first and second layers, the index of refraction of those layers varies with the depth of the layer between values greater than the second index of refraction and less than the first index of refraction.

Thus, by constructing an interference filter in the form of a multi-layer stack (on a substrate) comprising a

repeating group of layers, the group including at least a relatively high refractive index layer sandwiched between two layers of varying (but lower) refractive index, one may for example, provide an interference filter which substantially reduces or suppresses ripples, oscillations or transients of non-zero optical reflectance that would otherwise tend to occur outside the main reflectance band, and "higher order" reflectance bands, of the multi-layer stack. That is to say, the transmission spectrum of the resulting multi-stack filter will tend to vary substantially more monotonically within/across the pass-band of the filter, or if not monotonically then will at least oscillate with lesser amplitudes therein.

Furthermore, the present invention is able to reduce or substantially remove any discontinuity in refractive index and material composition/structure as between adjacent layers of a multi-layer stack. Consequently, since a portion of an inhomogeneous layer immediately adjacent a neighbouring layer is materially very similar (or identical) to that neighbouring layer, the bonding of the two layers in question at their interface is enhanced thereby strengthening the multi-layer structure at that interface.























































embodiments, such as would be readily apparent to the skilled person, are envisaged and may be made without departing from the scope of the present invention.























hereinbefore with reference to Figures 2a, 2b, 2c, 3  
or 4 of the accompanying drawings.









